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Research Article

Biomass and Carbon Stock Variation along slopes in Tropical Forest of Nepal: A case of Depard Community Forest, Makwanpur, Nepal

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Abstract
This study was conducted to assess biomass and carbon stock along slopes in Depard community forest, Manahari-6, Makwanpur district of Nepal. In Nepal, carbon stock estimation has been less practiced in community forest. A random sampling method was applied in this study to collect biophysical data i.e. DBH and height by non-destructive method to estimate the quantity of tree biomass and carbon stock. 21 sample plots with 1% sampling intensity were established within the study area. The circular area of 250 m^2 was predetermined with the radius of 8.92 m for this study. Secondary data were collected through published and unpublished literature. Data were pooled and analyzed with SPSS software. The total biomass and carbon stock were calculated to be 1381.30 t/ha and 649.21 t/ha, respectively. The biomass and carbon stock were highest (563.12 t/ha and 242.42 t/ha) in 0-5% slope, and lowest in >20% of slope (334.75 t/ha and 143.60 t/ha). The difference of biomass and carbon in slopes may be due to the accumulation of more organic matter and other minerals in the less sloped areas through rainfall, landslide.

Keywords: biomass, carbon stock, climate change, community forestry

1. INTRODUCTION

Globally, forest vegetation shares approximately 80% of terrestrial above-ground, and 40% of terrestrial below-ground biomass carbon storage [1]. Forest plays a significant role in the global carbon cycle as they acts as both sources and sinks of carbon, depending on specific management interventions and regimes [2]. Carbon is stored in carbon pools like standing forests, understory plants, leaf litter, soils, rocks, and sediments makes the forest function as both carbon source and carbon sinks [3]–[5]. About 43-50% of the dry biomass of trees is refered as carbon [6][7]. Growing forests have potential to sequester and stock carbon as biomass and mitigate global climate change [8][9]. Atmospheric carbon is acquired and stored in plant different parts in organic compounds form [10]. Soil sequester carbon by increasing soil organic carbon when a plant dies or the plant material decomposes in the soil then this carbon content can be released in the form of CO_2 through decomposition of plant biomass and the respiration of plant roots and soil microbes [11]. Forests sequestrate the highest carbon among the terrestrial ecosystem [12].

Biomass and carbon stock of trees vary among natural and plantation forests [13][14]; between climatic zones and management regimes [15]; and according to age classes and species density [16]. The protection of forests, regeneration, and plantation in degraded areas enhance the productivity and carbon stock [17]. Atmospheric carbon can be sequestered through increased volume of plantation forest lands which help to mitigate atmospheric CO_2 [18][19]. CO_2 is considered as one of the major Green House Gases (GHGs) [20]. More than 1 trillion tons of carbon are currently store by the world's forests and forest soils which are twice the amount of floating free in the atmosphere. Therefore, several forestry projects aids to lower the GHGs emissions in different ways either by preventing the carbon stored in standing forests from being released into the atmosphere or actively increase carbon stocks through tree planting, improved soil management or enhancement in natural regeneration of degraded forest lands [21]. Plantations act as a reservoir of biomass carbon [22]. Improved silvicultural

practices may enhance atmospheric carbon sequestration [12][23].

The scientists, policymakers, and the government are growingly concerned about climate change due to the continuous increase of GHGs concentration. In this sense, the interest in mounting carbon stocks in trees and substitution of fossil fuel by the use of tree biomass are also rising [24]. Globally, several studies have been performed on the role of tropical forests in climate change mitigation and possible effects on climate due to deforestation [25][26]. The magnitude of carbon change due to tropical forest deforestation is difficult to predict [8] as the tropical forest contain more species than any other ecosystems [27] and are large carbon sinks [28]. About 89% stored carbon get loss due to the loss of living biomass in the ecosystems [29]. It is essential to know the stocks of carbon as biomass per unit area for different forest types to assess the impact of deforestation and re-growth rates on the global carbon cycle. Therefore, both the Above Ground Biomass (AGB) and Below Ground Biomass (BGB) need to be measured for the better calculation of total forest carbon [30]. The forests and soil are necessarily conserved to maintain considerable amounts of carbon on the earth [31].

Aboveground biomass represents 60% of total tree biomass [23], hence, measured more importantly while calculating plant carbon pool [32]. Also, belowground biomass, deadwood biomass, and litter biomass are required to measure to determine total carbon stock by plants over a specific time [11]. It also helps to determine the effects of land-use change and deforestation on net carbon fluxes.

In Nepal, various studies have been performed on agroforestry focusing on tangible benefits; however, studies focusing on intangible benefits like carbon sequestration are very less in number [33]. Pradhan et al. [34] have estimated that the forests of Nepal stored 897 million metric tons of carbon (including Carbon in above-ground biomass, carbon in below-ground biomass, Sub-total: carbon in living biomass, carbon in dead wood, carbon in litter, Sub-total: carbon in dead wood and litter, and soil carbon to a depth of 100m) in the year 2005. Similarly, the carbon in aboveground biomass in the forests of Nepal for the year 1986 by physiographic regions was found to be 36 million tons in Terai, 76 million tons in Siwaliks, 67 million tons in the Middle mountains, 123.5 million tons in High mountain, and 11.5 million tons in High Himalaya. However, a few studies has been carried out in estimating carbon stocks both in the biomass and in the entire soil profile under different land use categories in Nepalese mountain watershed. Also, very little studies has been carried out in estimating carbon pools in vegetation (Above and below ground biomass) and in soil profiles under different forest types in Nepal [35][36]. The updated data on national forest inventory and technical capacity is poor, and the changes in forest cover biomass stock, carbon removal, and carbon emission are limited in

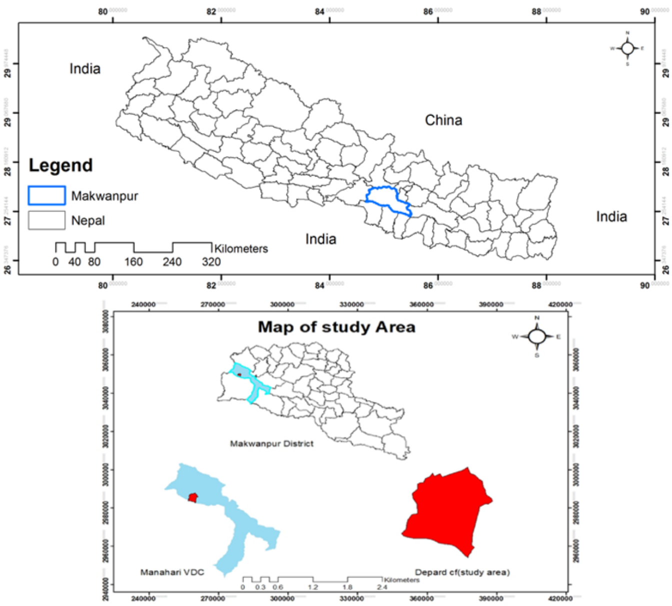

Figure 1. Map of the study area

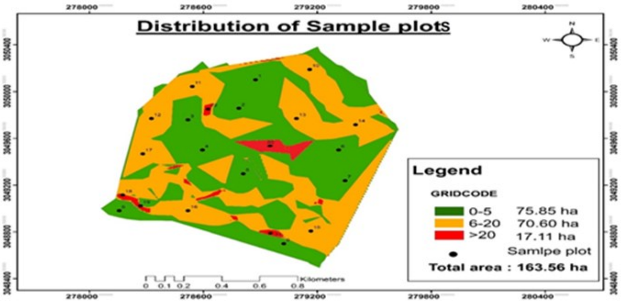

Figure 2. Distribution of sample plots

the developing countries like Nepal [36]. Community forestry has been given major priority of Nepal's forestry sector and during the last 30 years of community forestry implementation, more thean 25% of the national forest is handed to more than 14,200 Community Forest Users Groups (CFUGs) [37]. Despites protecting community forest by CFUGs for about last 30 years, forest and soil inventory has been paid little attention regarding carbon sequestration. Hence, amount of soil and biomass carbon sequestration is unknown [38]. Therefore, this study has endeavored to estimate the biomass as well as carbon stock and to compare biomass variation at the different slopes in Depard Community Forest of Makwanpur district, Nepal.

2. MATERIALS AND METHOD

2. 1. Study area

The study was performed in the Depard Community Forest of Manahari-6, Makwanpur district ($84^0$41' to $84^0$35'E longitude and $27^0$21' to $27^0$40'N latitude). The community forest occupies an area of 163.56 ha. The forest is mixed deciduous forest dominated by the species like *Schima wallichi* (Chilaune) and *Shorea robusta* (Sal). The district consists of several districts level roads which are reachable by Mahendra highway (47 km only) and Tribhuvan highway (110 km only). Mahabharat hills lie in the North and the Churia hills lie in the South of this district. Tropical and subtropical climate is found in the Churia range which lies in the southern part of the district while temperate climate is found in the Mahabharat range in the northern part [39]. Seasonal characteristics include cold, hot, and rainy seasons (each of four months) with an average relative humidity of 73.5 % in the district. Rapti and Bagmati are the major river system in this district. Most of the people in the district depend on subsistence farming for economy rather than industrial sector. About 80.7 % of the population depends on livestock and agriculture while 17.3% of them rely on small scale business sectors.

2.2. Methods

2.2.1. Data collection

Data was collected primarily through a direct field survey of biophysical measurement. The biophysical measurement i.e. Diameter at Breast Height (DBH) and height of trees was measured using Diameter-tape and Sunto-clinometer and Abney's label respectively. Forest inventory was conducted to estimate the present status of the forest. A random sampling method was applied to collect data for the estimation of tree biomass and carbon stock in the forest. A total of Twenty-one (21) concentric circular sample plots were laid out as per the forest carbon stock measurement guidelines with the radii of 8.92 m (for measuring trees and poles), 5.64 m (for measuring saplings), 1 m (for measuring seedlings) and 0.56 m (for taking the samples of the leaf litter, herbs, grass and soil) [40] along with 1% sampling intensity were randomly established within the study area referring to national inventory guideline developed by Department of Forest, Community and Private Forest Division [41] (Figure 2 and 3). The circular area of 250 m^2 was predetermined with a radius of 8.92 m for this study. All trees with DBH ≥ 5 cm were taken for estimation of biomass and carbon stock in the forest. Severals research findings, publications, other relevant literatures related with carbon and biomass estimation were reviewed to perceive the better understanding, interpretation and analysis of the research.

2.2.2. Data Analysis

Data were pooled and analyzed with SPSS software. Arc GIS 10.2 was used to fit a map. T-test

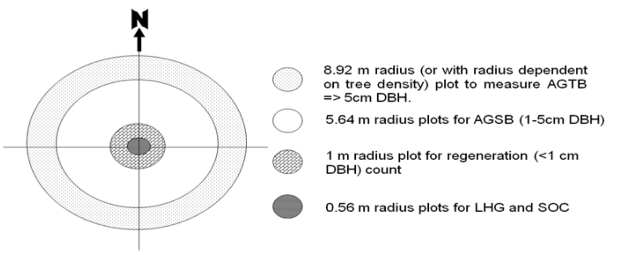

Figure 3. Sample Plot Layout

Table 1. Diameter and height distribution of trees per ha

No.	Slopes (%)	No. /ha.	Diameter (cm)			Height(m)		
			Min	Max	Average	Min	Max	Average
1	0-5	280	6.5	93.8	16.92	7	23	9.56
2	6 -20	200	10	95.6	21.95	7	19	9.38
3	>20	168	13.6	90.4	31.68	8	17	11.40

was applied to compare the average biomass in different slopes of the forest because T-test is performed to determine if there is significant difference between the mean of two groups from randomly sampled data. In this study, to determine significant difference between average biomass in different slopes of forest, T-test is used.

2.2.3. Biomass Estimation and Net Carbon Content

The biomass of each tree includes stems, branches, leaves, and roots. It can be divided as aboveground biomass which includes stem, branch, and leaves and underground biomass which include the root. The important characteristics such as volume and biomass were predicted by biophysical measurement i.e. Non-destructive methods and mathematical models by measuring Diameter at Breast Height (DBH) directly.

Above-ground biomass: A simplified standard regression model was used to calculate the biomass of the trees; it is based on DBH, height, and wood density [42]–[44]. AGB is calculated by the formula given by Chave et al [45].

$$(AGB) = 0.0509 * \rho D^2 H \quad (1)$$

Where, ρ= specific gravity of wood (gcm^{-3}), D= tree DBH (cm) and H= Height of tree (m).The obtained AGB value for the each individual weight (kg) of a sampling plot were summed up and divided by sampling plot area ($250m^2$). The biomass stock density value thus obtained is in kgm^{-2} which was then converted to t/ha by multiplying it by 10. The wood-specific gravity used for *Shorea robusta* is 0.88 as its specific gravity value ranges from 0.83-0.93g/cm^3 [46] and *Schima wallichi* is 0.689 g/cm3 as its specific gravity value ranges from 0.45-0.92 g/cm^3 [47].

Below Ground Biomass (BGB): It includes biomass of live roots (<2mm diameter). It was calculated by multiplying with AGB (0.26) [48].

$$\text{Below Ground Biomass (BGB)} = 0.26 \times \text{AGB (ton)} \quad (2)$$

Total Biomass: Total biomass is the sum of the above and below ground biomass [49][50]. It is calculated as:

$$\text{Total Biomass (TB)} = \text{AGB} + \text{BGB} \quad (3)$$

Net carbon content: The stock method was used to calculate biomass carbon; where carbon content is assumed to be approximately 50% of dry biomass [51]. The formulas used to calculate above ground carbon (AGC) and below-ground carbon (BGC) are:

$$\text{Total AGC} = (\text{Total AGB of the tree}) \times 47\% \quad (4)$$
$$\text{Total BGC} = (\text{Total AGOC}) \times 15\% \quad (5)$$
$$\text{Total carbon content} = \text{Total AGC} + \text{Total BGC} \quad (6)$$

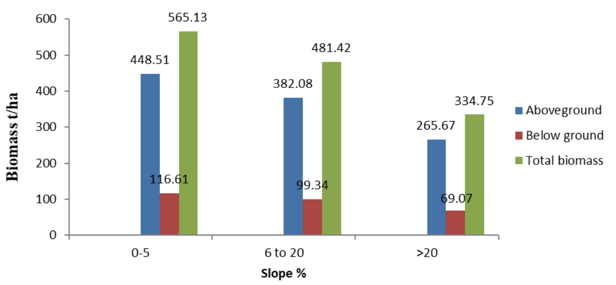

Figure 4. Estimated Biomass of the forest (ton/ha)

3. RESULT AND DISCUSSION

3.1. Diameter and Height distribution

The total number of trees was found to be 280, 200, and 168 per hectare in 0-5 %, 6- 20 %, and >20 % of the slope respectively in the forest. The average diameter was 16.92 cm, 21.95 cm, and 31.68 cm and average height was 9.56 m, 9.38 m, and 11.40 m for the trees in given slopes

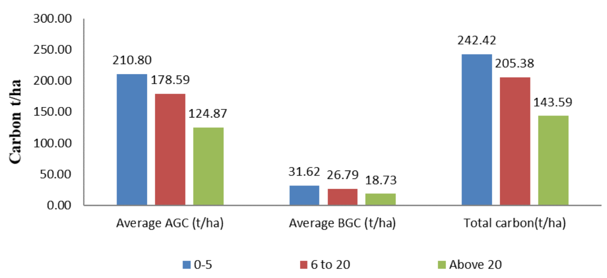

Figure 5. Carbon stock in the forest (t/ha)

respectively (Table 1). The better frequency of the forest tree species was found in lower and medium slope area due to the presence of stable environmental conditions [52].

This studied shows relatively low stem density (216 trees/ha) on average, however densities reported by Timilsina et al. [53] (220 trees/ha) in Bardia National Park a somewhat exceeded our overall mean. Meanwhile, Rautiainen measured similar densities (152–264 trees/ha) in Sal forest in the Bhabar–Terai zone of Nepal [54].

3.2. Biomass Estimation

The total biomass was found to be 565.13 t/ha, with AGB 448.51 t/ha and below-ground biomass to be 116.61 t/ha in 0-5 % of slope in the forest. In 6-20% of the slope of the forest, the total biomass was found to be 481.42 t/ha with above-ground tree biomass 382.08 t/ha and below-ground root biomass to be 99.34 t/ha. Similarly, the total biomass was found to be 334.75 t/ha with above-ground tree biomass 265.67 t/ha and below-ground root biomass to be 69.07 t/ha in >20 % of a slope of the forest (Figure 4).

Another study done by Maren and Sharma in Himalayas Mountain forests [55] showed the average above ground live biomass as 164 tons/ha which is slightly less than this study. Aboveground biomass varied from site to site because of varying plant community structures, variation in plant species and the succession stage of the forest.

The total biomass and total carbon stock are highest (563.12 t/ha and 242.42 t/ha) in 0-5% slope of the forest, followed by 6-20% of slope (481.42 t/ha and 205.38 t/ha) and lowest in >20% of slope (334.75 t/ha and 143.60 t/ha) in the study area (Figure 4 and Figure 5). The highest biomass and carbon stock in the 0-5% slope may be due to a higher density of trees (280 trees/ha) compared to 6-20% and >20% slope. More the tree density higher is the biomass [56]–[58]. The present study suggests that total biomass and carbon stock varies from site to site i.e. varies with slope in the forest. Altitudinal variation along with slope gradient has an impact on above ground carbon and below ground carbon because of its influence on soil water regime [59].

3.3. Carbon Estimation

The total carbon stock was found to be 242.42 t/ha with an average above-ground tree carbon stock 210.80 t/ha and average below ground root carbon stock to be 31.62 t/ha in 0-5 % of a slope. In 6-20% of slope, the total carbon stock was found to 205.38 t/ha with an average above-ground tree carbon stock 178.59 t/ha and average below ground root carbon stock to be 26.79 t/ha. Similarly, the total carbon stock was calculated to be 143.60 t/ha with an average above-ground tree carbon stock 124.87 t/ha and an average below-ground root carbon stock to be 18.73 t/ha in > 20 % of the slope of the forest (Figure 5). Around 53% of carbon stock was found in the forest area with slope 0-5% , while 41% carbon stock was present in the forest with slope gradient of 6-20%. Similarly, in the forest area with more than 20% of the slope, 7% carbon stock was present (Figure 6). Not only in the sal dominated forest, similar result was found by Feyissa et al. [60] while studying on Egdu forest. Moreover, Maggi et al. [61] also concluded very steep slope areas contain little vegetation cover compared to low slope areas. On the contarary, Zaki et al. [62] studied the forest carbon stock on tropical lowland dipterocarp forest and revealed that above ground carbon stock and below ground carbon stock tends to increase with slope. The distribution of biomass and carbon stocks in the forest is known to vary due to the presence of various tree species,

Table 2. Paired t-test

S1	S2	S3	M1	M2	M3	N1	N2	N3
109.77	96.92	124.10	565.13	425.58	185.97	9	8	5

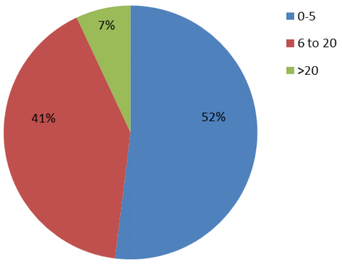

Figure 6. Carbon composition of forest (ton)

nutrient availability in soil, climate, and other disturbance regime too [59]. In the national scenario, the Terai consists of a large amount of total organic carbon (479.29 t/ha) as compared to the average carbon stock of tropical forests of the world (285.0 t/ha) [63]. But it is lower than the average carbon stock of the community forests of Nepal [64]. The sparse and dense area has 89.2 t/ha and 129.0 t/ha carbon in the Kayerkhola watershed dominated by *Shorea robusta* forest in the Chitwan district [65].

The AGB and BGB are highest (448.51 t/ha and 116.61 t/ha) in 0-5 % and lowest (334.75 t/ha and 69.07 t/ha) in >20 % of a slope the forest. Similarly, above-ground carbon stock and below-ground carbon stock were highest (210.80 t/ha and 31.62 t/ha) in 0-5 % of slope and lowest (124.87 t/ha and 18.73 t/ha) in > 20 % of slope of the forest. Carbon composition is highest (53%) in 0-5% of slope and lowest (7%) in >20% of slope in the forest. Tree biomass and carbon stock has inverse relation with slope [66]–[68] and our result in this study supports the growing indications that forest ecosystems growing at lower slope store higher amounts of carbon than forest ecosystems at higher slopes. Both the above-ground and below-ground measurements should be carefully performed for precise estimation of biomass and carbon stock [58]. Our study shows quite greater biomass and carbon stock than other studies which can bey supported by the study conducted by Yohannes which concludes that the highest amount of carbon stock was found in middle altitude area dominated by *Shorea robusta* and *Termanalia tomentosa* [52].

3.4. Comparison of average biomass in different slopes of the forest

The estimated amount of average biomass in the different slopes of the forest was compared by using a T-test. The result is mentioned in (Table 2 and Table 3).

Since T calculated value is more than T tabulated value. Hence, it is concluded that biomass at different slopes in the forest is significantly different.

4. CONCLUSION

In the study of the biomass and carbon stock in the Depard Community Forest, the measurements was found to be highest (563.12 t/ha and 242.42 t/ha) in 0-5% slope of the forest, followed by 6-20% of slope (481.42 t/ha and 205.38 t/ha) and lowest in >20% of slope (334.75 t/ha and 143.60 t/ha) in the study area. This is related with the distribution of productive stem density within the forest as different areas with different slope varied significantly in the number, diameter and height of the tress as well. Moreover, the ability of carbon sequestration varies according to the site, presence of invasive alien species, tree density, fodder collection, species richness, gazing, canopy cover/strata, slope, and aspect, etc in different sites. Significant difference in the biomass and carbon stock along the slope gradient was also proven by T-test. This research provides the baseline data on the slope and biomass significance in study area and further study through LIDAR technology is recommended as well.

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Table 3. Unequal variances

Test between	0 to 5 and 5 to 20	5 to 20 and >20	0 to 5 and >20
Df	15	11	12
T-calc	0.0091	0.0103	0.0081
T-tab	0.0002	0.0082	0.0034

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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